THEORETICAL AND EXPERIMENTAL INVESTIGATION OF A THREE-DIMENSIONAL MAGNETIC-SUSPENSION BALANCE FOR DYNAMIC STABILITY RESEARCH IN WIND TUNNELS

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The work being done under NASA Grant NGR-47-005-029 by an enthusiastic group of staff members and graduate students is proceeding at a fairly large and satisfactory rate. The current phase is the design phase for the cold magnetic balance prototype, and is dominantly close, detailed and interacting studies and analyses. Within a short length of time most of the design details will be frozen. It is considered that a detailed technical status report would be much more appropriate and efficient at a little later time. Consequently, the present status report will be brief and summary in character with the intent and expectation that the next status report will be quite detailed and technical. Therefore, the following body of this paper will consist of brief summaries of the status with respect to the various pertinent items involved in the project.

1. Philosophy. The original basic philosophy of the cold magnetic balance prototype project is unchanged. The basic objective is to demonstrate the feasibility of the University of Virginia cold balance system to study dynamic stability in a wind tunnel. The basic philosophy is to develop the 6" prototype system in such a way that its extrapolation to a larger tunnel size may be made with the maximum of confidence. The only changes that have occurred are concerned with details of how confident extrapolations may best be made.

2. Cryogenic and Coil Systems. The tentative initial concept involved the use of high purity aluminum coils refrigerated to about 20°K, which would require a closed cycle, cold helium gas (not being willing to risk the hazzard of a liquid hydrogen or the expense of a liquid neon system) refrigerator system. An additional initial concern was the uncertainties related to AC operation of superconducting (the alternate approach) gradient coils. First, the decision was made to go with superconducting main field and drag augmentation (study currents) coils, and in the interest of simplicity a liquid helium (4°K) cooling system for the entire coil assembly. Next, the decision was made to use highly copper-stabilized superconducting coils for the gradients coils also, accepting the uncertainties in their AC operation. Several points were involved in these decisions:

a) Should the gradient coils go entirely normal (in some specific mode of operation), the copper can carry the current without catastrophy but with larger than desirable heat production.

b) Liquid helium cooling with a reasonable reservoir capacity of the liquid permits rather large dissipation rates for reasonable times, subject only to maximum heat transfer limitations (this limitation is much larger for liquid than gaseous helium).

c) The currently anticipated mode of operation (item 3) will result in less gradient coil current variations and therefore hopefully smaller AC losses.

d) It is anticipated that superconducting coil systems will prove eventually to be the better approach to the cold magnetic balance and thus seems more fundamentally appropriate in the prototype.

A major consequence of these decisions is that the purchase of a cryogenic refrigerator for the system is not appropriate. Rather, liquid helium will be purchased (the convenient supplier will be the Physics Department of the University of Virginia) and the gaseous helium returned via pipeline. The coil systems are designed and out on bid. A remaining design problem concerns the structure of the inner cylindrical dewar well and involves the interaction of superinsulation with the model position sensing system.

3. Model Motion Degrees of Freedom. In the initial concept, the model under study in the wind tunnel would be essentially free in rotation and the magnetic sphere (around which the model is built) would either be held nearly fixed in position or would be driven to execute simple motions. As detailed study and analysis of balance system and model characteristics proceeded, it became apparent that such a mode of operation was not required and would be difficult and costly to provide. Thus the group has acquired the concept of the quasi-6°-of-freedom mode of operation, as distinct from the initial concept which could be termed a 3°-of-freedom mode of operation. The basic idea is that the balance system, considered as a support system, sees and responds to

translational changes in the sphere position of a frequency less than a certain balance response frequency and does not "see" or try to respond to oscillations in the sphere position at higher frequencies.

The following points are pertinent:

a) A number of effective controls, aerodynamic and nonaerodynamic in origin, are available to adjust the range of resultant oscillation frequencies of the model in the wind tunnel. For example, even an aerodynamically-unstable model may be stabilized by using a prolate spheroid as the magnetically-supported core of the model providing the quite interesting prospect of accurate studies of aerodynamically unstable configurations.

b) The ratio of translation amplitude to angular amplitude decreases as the oscillation frequency increases, which permits the satisfaction of system-fixed translation amplitude limits for reasonable frequencies.

c) Typical high-lift configurations pose the practical impossibility (due to the speed and force capacity of the balance system required) of holding the sphere position fixed at appreciable angular amplitudes.

d) Subject to a probable (but hopefully not too large) reduction in the accuracy of observing the motion parameters, the quasi-6°-of-freedom mode of operation presents no fundamental problem in the extraction of the desired aerodynamic information.

e) Quasi-6° operation considerably aids the basic balance problem; e.g., the AC superconducting gradient coil losses are certain to be smaller.

f) A considerable and favorable interaction with the power supply problem occurs.

g) The detailed studies have revealed the need for considerably larger drag augmentation force capacity than initially specified and have emphasized the importance of the recognized model launch problem (especially for high-lift configurations).

4. Aerodynamic Data Systems. For quantitative study, the unchanged, basic idea is that observations of the motion of the model and the balance forces and (if any) moments on the model are made, this information is inserted into the equations of motion, and the aerodynamic forces and moments are extracted and suitably interpreted. Observation of the balance forces and moments is straightforward. Considerable study has been devoted to systems to observe the model motion. A system involving longitudinal lines scribed on a (cylindrical or conical) section of the model near the sphere appears very promising. However, since it appears likely that the optimum aerodynamic data acquisition system depends sensitively on the tunnel (and model) size, it does not seem appropriate to devote a large effort in the prototype project to data acquisition since direct extrapolation to large tunnels and models is not likely to occur. Consequently, a simpler, less accurate system probably will be chosen for the prototype. Should the prototype system remain at the University of Virginia as a research tool when the prototype project is over, a precision data acquisition system will almost surely become highly desirable.

The above remarks are based on the point of view that maximum, quantitative information is to be extracted with no restriction on the character of the information. Simpler situations are quite likely to be present or arrangeable in certain cases. For example, if the model motion obeys a set of linear equations with constant coefficients, pertinent information may be extractable by simple observations; e.g., a frequency.

5. Sphere Position Sensor. The decision has been made to use a modified MIT system to detect the sphere position and provide the balance error signal. A similar system to observe model roll rates is under study. Bench tests are getting underway.

6. Gradient Coil Power Supplies. It was recognized initially that the gradient coils would be an important problem. Even for no dissipation in the coils, the necessity of increasing or decreasing the coil field energy in a

sufficiently short time corresponds to a rather large positive or negative power. The uncertainty was the magnitude of the problem. The initial concept of cold, high-purity aluminum coils and the associated closed, cold helium gas refrigerator dictated a symmetrical (about zero current) mode of operation to minimize dissipation. The bi-directional operation further complicated and increased the cost of the power supplies. Further, the 3°-of-freedom operation concept, requiring the speed and force capacity to hold the sphere fixed, greatly increased the power supply problem. In toto, the initial power supply estimates were virtually unfeasible.

However, the decision to use stabilized superconducting coils coupled with the recognition that the Quasi-6°-of-freedom mode of operation is appropriate, if not more desirable, has greatly reduced the power supply problem by allowing unidirectional operation and reducing the required response time and force capacity. Present power supply estimates for the prototype are reasonable.

It is interesting to note that, on the approximately valid assumption that the power supply cost is directly proportional to the product of peak field energy and response frequency and on the basis of crude estimates of certain factors, one can estimate how the power supply costs scale with tunnel size. Conservative estimates show that power supply costs surely scale better than the square of the scale factor and perhaps may scale as the first power. The drag augmentation coils and the main field coils, operated at DC or very low frequency, constitute no significant problem.

7. The Control Problem. Considerable study has been devoted to the control problem and little or no change has occurred in its important aspects. For large disturbances the bang-bang (or minimum time) control low is envisioned and for small disturbances about some operating point a linear (proportional and derivative perhaps plus integral) control low will be used. Thus the frequency response to small disturbances will, or can, be significantly larger than the effective frequency response to large disturbances. It is difficult to determine appropriate relative values of response time and force capacity, partly because

the precise character of the disturbances the model will see are uncertain. Rough estimates can be arrived at by specifying allowable translations. Since force capacity can be increased at constant response time by adding identical power supply units, it is expected that conservative estimates of required response speed will be made.

8. General Theoretical Studies. Continuing theoretical studies related to the various aspects of the cold magnetic balance system, its operation, and its use are being conducted. These include characteristics of the motion of specific models, relative accuracy of motion data and parameter values extracted, possibilities of the separation of certain parameters, scaling laws, etc.

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